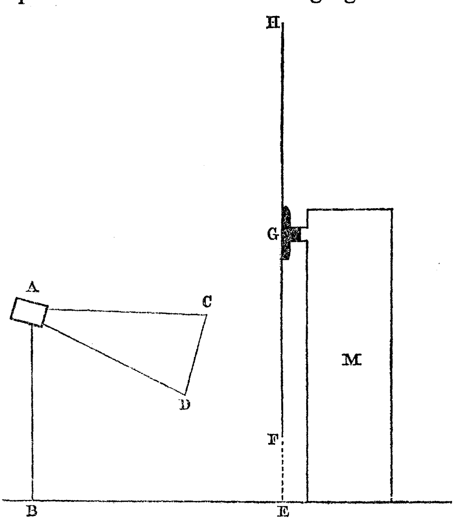
VII. "On the Heating of a Disk by rapid Rotation *in vacuo*." By Balfour Stewart, M.A., F.R.S., and P. G. Tait, M.A. Received June 1, 1865.

1. The authors were led, by certain views which they entertain regarding the loss of energy by a body, to make experiments in order to test these views, and about the end of 1863 they obtained results in air, which encouraged them to have constructed an apparatus wherewith to procure rotation *in vacuo*.

2. The apparatus for this purpose was devised and executed by Mr. Beckley, mechanician at the Kew Observatory, at which place the experiments about to be described were made. In this apparatus a slowly revolving shaft is carried up through a barometer tube, having at its top the receiver which it is wished to exhaust. When the exhaustion has taken place, it is evident that this shaft will revolve in mercury. In the receiver the shaft is connected with a train of toothed wheels, and ultimately causes a circular disk to revolve 125 times for each revolution of the shaft. The disks used have a diameter of 13 inches, and their plane is vertical. Two insulated wires, connected with a Thomson's reflecting galvanometer, are carried through two holes in the bed-plate of the receiver, and are then connected with a thermo-electric pile, having the usual reflecting cone attached to it. The outside of the pile, and of its attached cone, is wrapped round with wadding and cloth, so as to be entirely out of the reach of currents of air. The vacuum-gauge is on the siphon principle; it was constructed by P. Adie, and there is every reason to believe that it is perfectly deprived of air. The following figure will render the arrangements clear:



A B = 6 inches.
B E = 8 "
E G = $8\frac{1}{2}$ "
F H = 13 " (diam. of disk.)
A C = $5\frac{1}{4}$ "
C D = $2\frac{1}{2}$ "
M. Multiplying gear.

and it is only necessary to add that the whole is covered over with an air-tight glass shade, 15 inches in diameter and 16 inches high.

3. The deflection of the galvanometer-needle, produced by heating the pile, is recorded by means of a small mirror attached to the needle, which, as it moves, causes the reflected image of a line of light to travel over a graduated scale. The galvanometer-needle is rendered very nearly astatic by means of an auxiliary magnet; and this arrangement can be made so sensitive that if the temperature of the disk, exposed to the cone as in the figure, were to rise 1° Fahr., this would be denoted by a change in the position of the line of light equal to fifty divisions of the scale.

4. In these experiments the disk was rotated rapidly for half a minute, and a heating effect was, in consequence of this rotation, recorded by the pile. The object of this paper is to investigate the origin of this heating effect.

5. In this investigation the authors prefer discussing the effect produced on a metallic disk. The metal aluminium was chosen, from its lightness, so as to diminish the weight upon the bearings as much as possible. The reason for preferring a metallic disk is that the heat produced in this case affects the whole substance of the disk, and can thus be approximately measured. The disk of this metal employed was $\frac{1}{20}$th of an inch thick and 13 inches in diameter; it weighed ten ounces, and in most of the experiments it was covered with a coating of lampblack, applied by means of negative photographic varnish. In some of the experiments a plate of rock-salt, tightly secured in a brass fitting, was screwed upon the mouth of the cone. When this was done, a small piece of anhydrous baryta was placed within the cone to keep the inner surface of the salt dry, and a dish containing strong sulphuric acid was likewise placed in the receiver. Indeed the latter was always used; so that in the results obtained the residual air may be considered as nearly dry, and the surface of the disk, as well as that of the rock-salt, when this was used, nearly free from moisture.

Furthermore, in order to obviate the objection that the electric currents which take place in a revolving metallic disk might alter the zero of the galvanometer, the position of the line of light was read before the motion began, and immediately after it ceased, the difference being taken to denote the heating effect produced by the rotation. The turning was made in this way:—As soon as full speed was obtained, which might be about 10 seconds after beginning the motion, a chronometer was noted, and the handle was turned at a uniform rate for 30 seconds, and thereafter stopped as soon as possible. The most convenient speed *in vacuo* was found to be 20 revolutions of the handle, or 2500 of the disk, in 30 seconds. It is believed that the heating effect recorded may be considered as due to about 40 seconds at full speed.

6. The *thermometric* value of the indication given by the galvanometer was found in this way:—The disk was removed from its attachment and laid upon a mercury-bath of known temperature. It was then attached to its spindle again, being in this position exposed to the pile, and having a temperature higher than that of the pile by a known amount. The deflec-

tion produced by this exposure being divided by the number of degrees by which the disk was hotter than the pile, we have at once the value in terms of the galvanometric scale of a heating of the disk equal to 1° Fahr.

7. The following sets of experiments were made with blackened aluminium disk and rock-salt in the cone.

No. of set.	No. of observations in each set.	Time at full speed.	No. of turns of handle at full speed.	Heat indication. ° Fahr.	Tension of air in inches.
I.	3	30	20	0·85	0·3
II.	4	30	20·5	0·87	0·3
III.	4	30	20	0·81	0·3
IV.	3	30	20	0·75	0·65

8. A piece of wood precisely similar to the rock-salt plate was next inserted into the fitting of the latter, and after rotation there was no indication whatever. Hence the above effect (art. 7) is due to radiant heat, and not to currents of heated air reaching the pile. Again retaining the rock-salt, the interior of the cone was covered by black paper, and the effect upon the pile was very much diminished: this also goes to prove that the effect (art. 7) is due to radiant heat; and it now remains to discover whether this radiant heat comes from the rock-salt or from heated air, or from the surface of the disk.

9. The following sets of experiments were made with blackened aluminium disk, but without rock-salt.

No. of set.	No. of observations in each set.	Time at full speed.	No. of turns of handle at full speed.	Heat indication.	Tension of air in inches.
V.	3	30	20	0°·92	0·37
VI.	3	30	20	0·93	0·60

And when a black paper cover was introduced into the cone, other things remaining as before, the indications of the galvanometer were greatly diminished. The effect produced without rock-salt is therefore also a radiant heat effect; and as the indications (in terms of temperature) are as large as when rock-salt was used, we may conclude that the effect of art. 7 was to no perceptible extent due to heating of the rock-salt, otherwise it would have been diminished when the plate of rock-salt was taken away. Besides, as rock-salt is a bad radiator and a good absorber of its own heat, the plate would have had to be heated perhaps as much as 15° or 20°, in order to furnish a radiation equal to 0°·8 from the disk. On both these accounts it is impossible to believe that the effect was due to heating of the rock-salt.

10. Nor is it probable that the heating effect is due to radiation from heated air, since in order that nearly dry air of such a tenuity might give such a radiation, it would require to be heated enormously. But another proof that the effect is not due to air is afforded by removing the black from the aluminium disk and leaving it a rough metallic surface, when

the indication afforded by the galvanometer is reduced to about one-fourth of the amount with the blackened disk.

11. It only remains that the heating effect proceeds from the disk, and since the heat-indication afforded by the galvanometer-needle remains nearly constant for some time, this effect must be due to the heating of the whole substance of the disk.

12. Presuming, therefore, that the entire substance of the disk is heated, the next point is to ascertain the cause of this heating effect.

Now, in the first place, it cannot be due to conduction of heat from the bearings, for in some of the experiments the disk was insulated from its bearings by means of a plate of ebonite, and the result was the same.

Again, it is not due to revolution under the earth's magnetic force, for Professor Maxwell has kindly calculated the effect due to this cause under the conditions of the experiment, and he finds it infinitesimally small. Nor is the effect due to the condensation of vapour of water upon the surface of the disk. In some of the experiments, when the vacuum was newly made, there appeared to be a strictly temporary effect, due probably to moisture, which *increased* the range of the needle, but only during the time when the motion was taking place, for it very soon assumed its permanent position. In other experiments, when the air was very dry, there appeared to be a temporary cold effect of a similar description; but in all cases when the vacuum was kept long enough for the sulphuric acid to act, the only effect was a permanent one in the direction of heat, and this is that which has been described in these experiments. This permanent heating effect cannot, therefore, be due to the condensation of aqueous vapour, and indeed it is impossible to suppose that in the presence of sulphuric acid so much vapour should remain suspended in air of so low a tension as to produce a permanent effect so very considerable by its deposition.

13. In this endeavour to account for the heating effect observed, it would appear that we are reduced to choose between one of two causes, or to a mixture of the two.

(1) It may be due to the air which cannot be entirely got rid of.

(2) It is possible that visible motion becomes dissipated by an ethereal medium in the same manner, and possibly to nearly the same extent, as molecular motion, or that motion which constitutes heat.

(3) Or the effect may be due partly to air and partly to ether.

14. Now, if it be an air effect, it is not one which depends upon the mass of air. For (art. 7) the effect for a vacuum of 0·3 in. is as large as for one of 0·65 in.; and also (art. 9) the effect for a vacuum of 0·37 in. is as large as for one of 0·60 in.; and further, in some approximate experiments, the effect produced upon a wooden disk, in a vacuum of 4·0 in. and 2·0 in., was found to be the same as in one of 0·5 in., or very nearly so. It may therefore be presumed that only a very inconsiderable portion of the effect observed depends upon the mass of air left behind. It would, however, appear, from the views of Professor Maxwell and Mr. Graham, that there is

another effect of air, namely, fluid friction, the coefficient for which they believe to be independent of the tension; and as far, therefore, as this effect is concerned, little is gained by diminishing the amount of the residual air. It would appear, however, that the fluid friction of hydrogen is much less than that of atmospheric air; so that, were the heating effect due to fluid friction, it ought to be less in a hydrogen vacuum. An experiment was made with this purpose; and, other circumstances being precisely similar, it was found that in a hydrogen vacuum the heating effect due to rotation was 22·5, while in an air vacuum it was 23·5. These numbers may probably be considered as sensibly the same, and this experiment would therefore appear to denote that the effect is not due to fluid friction.

15. The authors, in submitting these remarks to the Royal Society, do not suppose that their experiments have yet conclusively decided the origin of this heating effect, but they hope by this means to elicit the opinions of those interested in the subject, which may serve to direct their future research.

VIII. "On the Fossil Mammals of Australia.—Part II. Description of an almost entire Skull of *Thylacoleo carnifex*, Ow." By Professor Owen, F.R.S., &c.

(Abstract.)

In this Part the author gives additional cranial and dental characters of the extinct marsupial carnivore, *Thylacoleo,* deduced from examination of better-preserved fossils, obtained from freshwater deposits in Darling Downs, Queensland, Australia.

The forepart of the skull, wanting in the first-described specimen from similar deposits in the province of Victoria, is preserved in the present specimen, showing the premaxillary bones, which are relatively larger than in placental felines. Each bone has three teeth, of which the foremost is developed into a tusk, the second and third being very small. There is no canine, or no tooth developed as a laniary in the maxillary bone. In the short extent of the alveolar border of this bone between the great carnassial molar and the maxillo-premaxillary suture, there are two approximate small round sockets, which lodged either one double-rooted tooth or two small single-rooted teeth. But dental development has mainly expended itself upon the perfection of a pair of laniary incisor tusks, in both upper and lower jaws, for piercing, tearing, and holding, and a pair of carnassials in both jaws for flesh-cutting. These, in the present specimen, closely agreed with those described in the former one, but were more worn: they are the largest examples of these peculiarly modified shear-blade teeth in the mammalian class. Although the tusks are incisors—not, as in placental carnivora, canines—they possess, through the singular shortness of the facial part of the skull in *Thylacoleo,* the same mechanical advantage, in their proximity to the biting-power of the enormously deve-